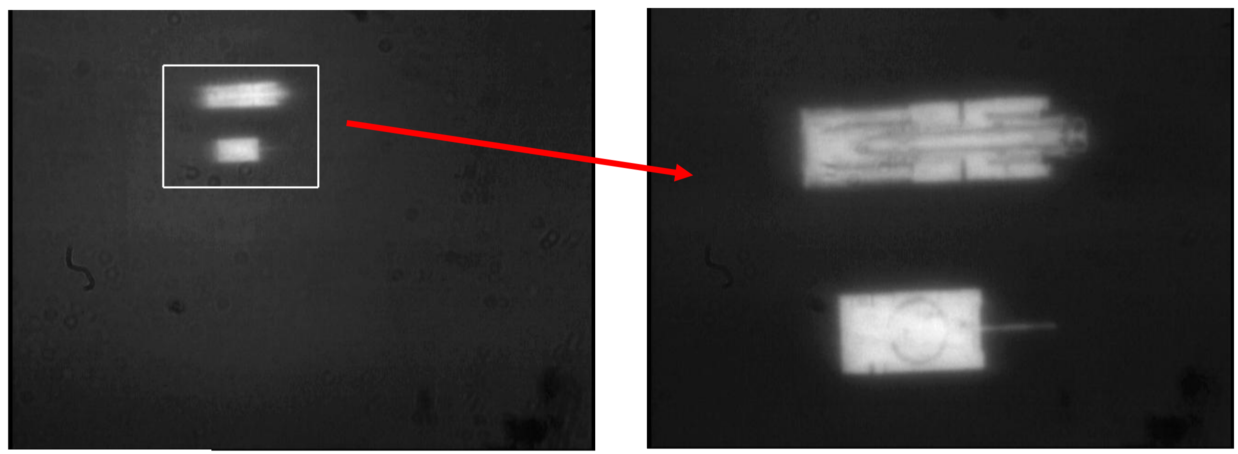
Adaptive optical zoom for space-based imaging

Mirror Technology Days
July 31, 2007



David Wick, Ty Martinez, Brett Bagwell, Gary Peterson, Bill Cowan, Bill Sweatt, Olga Spahn, Sergio Restaino, Don Payne, Jonathan Andrews, Christopher Wilcox, Robert Romeo, and Robert Martin

narrascape

Breault Research

Composite Mirror Applications

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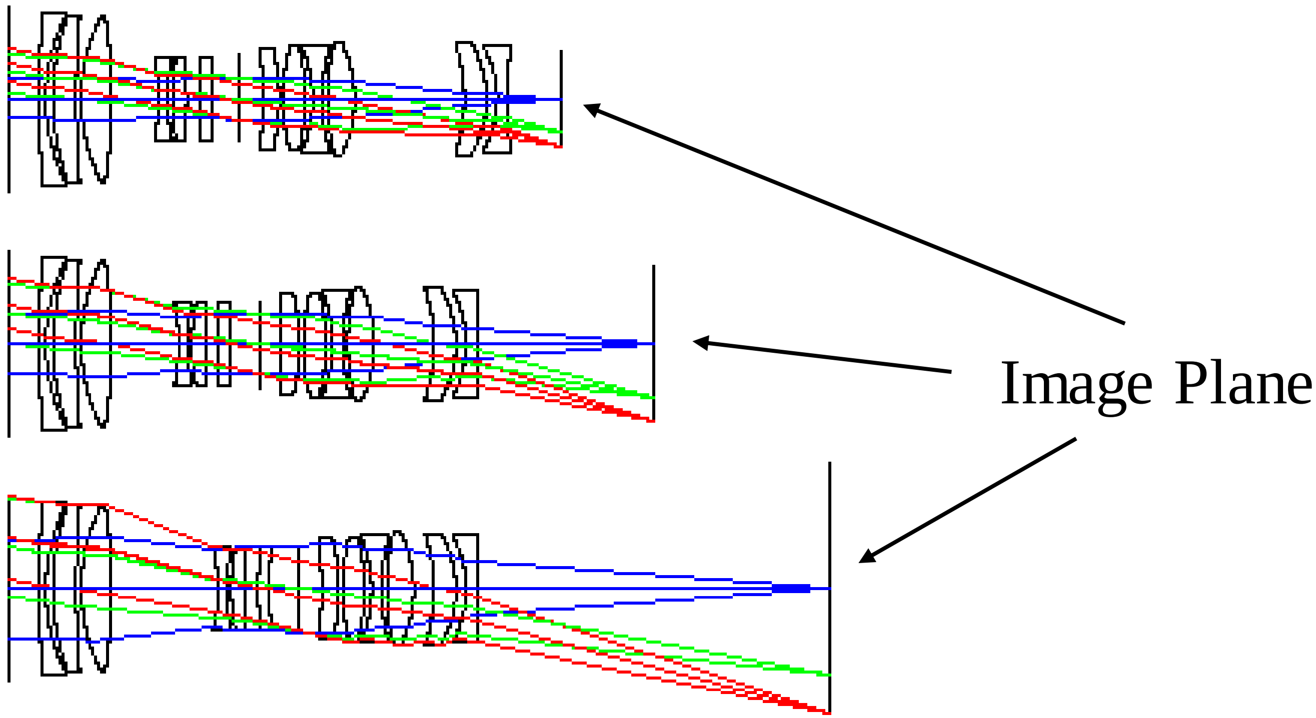
ZEMAX Layout
Conventional 2.5X Zoom

Wide field-of-view



Narrow field-of-view – ON AXIS

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Optical Zoom vs. Electronic (Digital) Zoom

Electronic (Digital) Zoom

4X Optical Zoom

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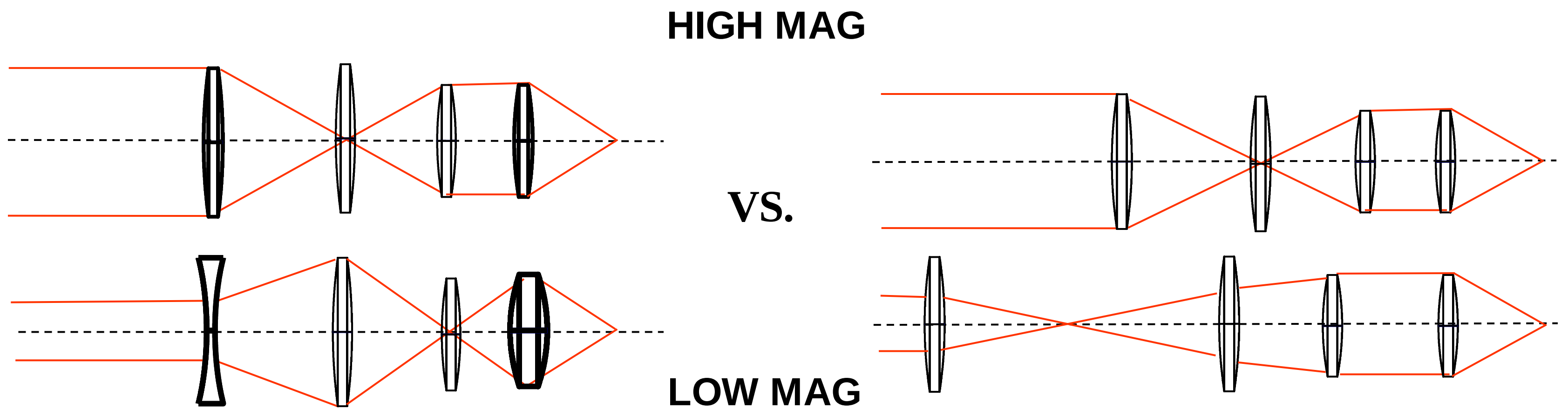
Adaptive Optical Zoom vs Conventional Zoom

Small changes in the individual focal lengths of individual elements (lenses or mirrors) yield much larger changes in effective focal length and magnification of the system.



- Power consumption can be greatly reduced

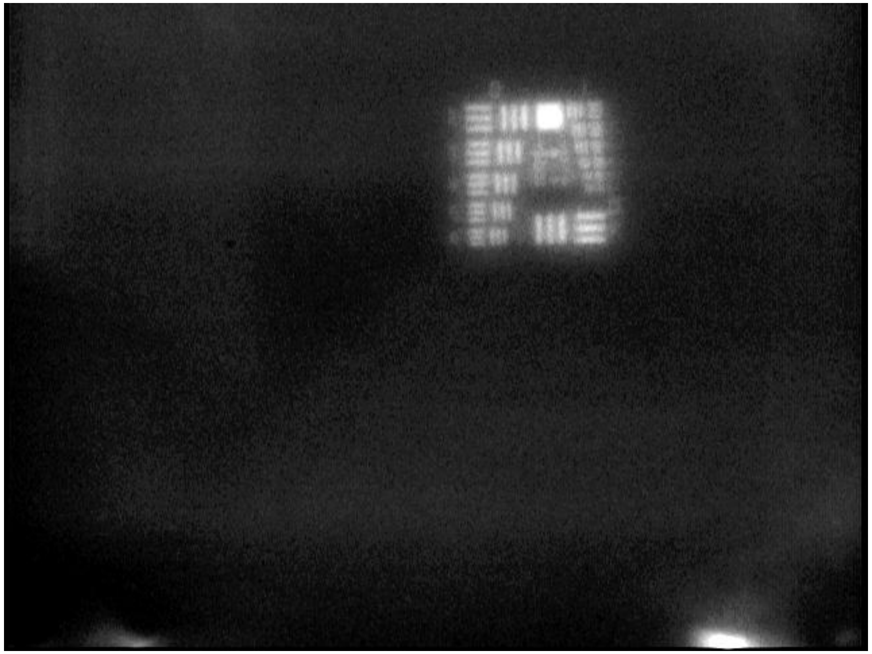
…deflection of a membrane vs. moving glass.

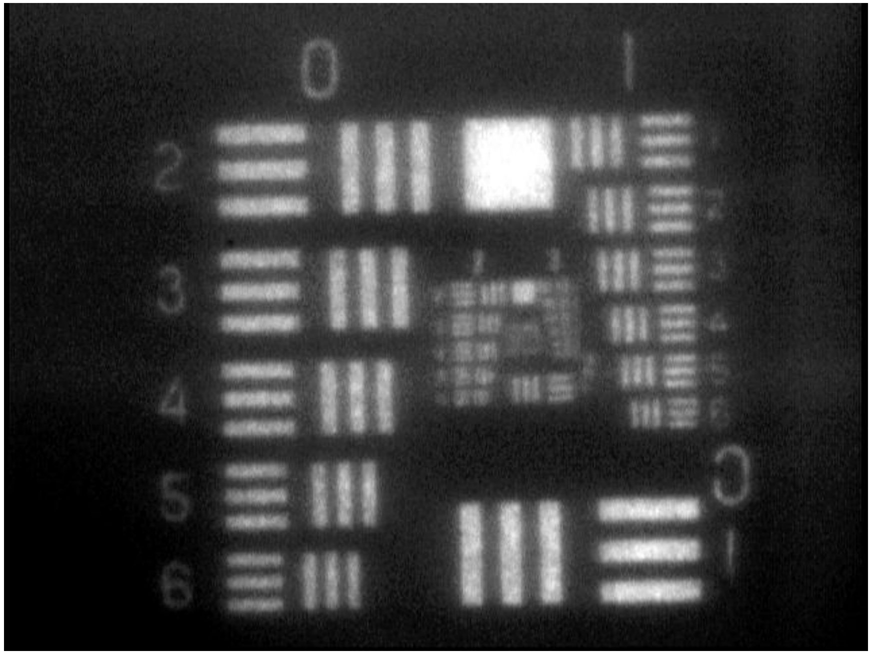
Why Adaptive Optical Zoom?
NONMECHANICAL

- **Optical magnification**
  - **Switch between wide area surveillance mode and high-resolution identification/ tracking mode in milliseconds**
  - **Higher resolution over <u>ANY</u> area-of-interest within wide field of view – Do <u>NOT</u> have to be pointed at area (i.e. on-axis) as in conventional zoom system**
- **Gimballess tracking and rapid retargeting**
  - **Track targets without mechanical gimbals or steering mirrors**
  - **Zoom-in on <u>multiple</u> targets without steering optics in milliseconds**
  - **Optimize centroid tracking for improved tracking/laser comm performance**
- **NO macroscopic moving parts – Very Fast (20 Hz – 1 kHz)**
  - **No moving lens elements, gears or cams for optical zoom**
  - **No gimbals or steering mirrors for redirecting ‘gaze’**
  - **Low power consumption (mW)**
  - **No inertia, doesn’t require momentum compensation on platform**

U.S. Patent #6,977,777

Liquid Crystal SLM
Adaptive Optical Zoom





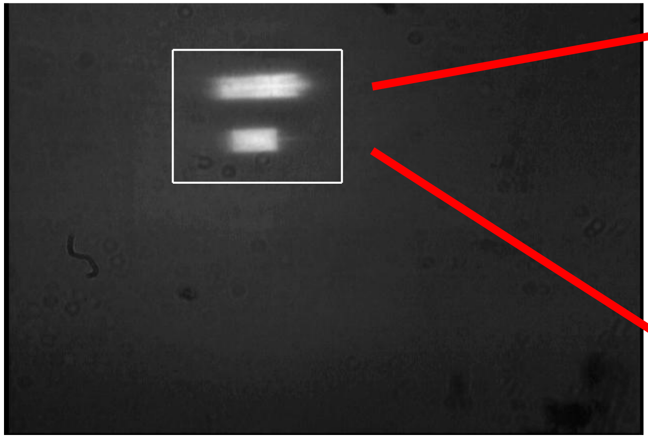
Current experimental results for 3.3X zoom

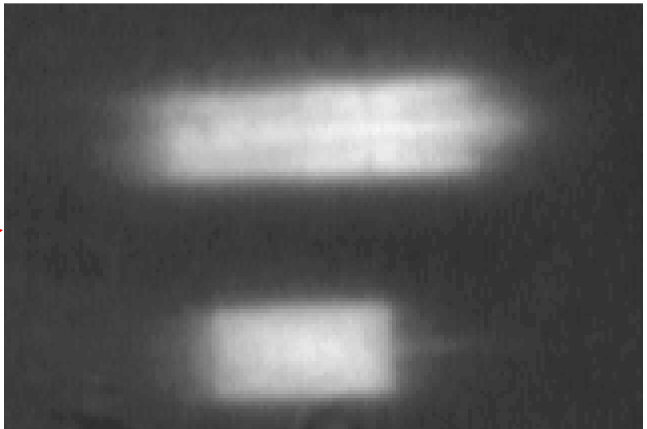
Uses two liquid crystal SLMs as active lenses

Note : Magnification is NOT on axis.

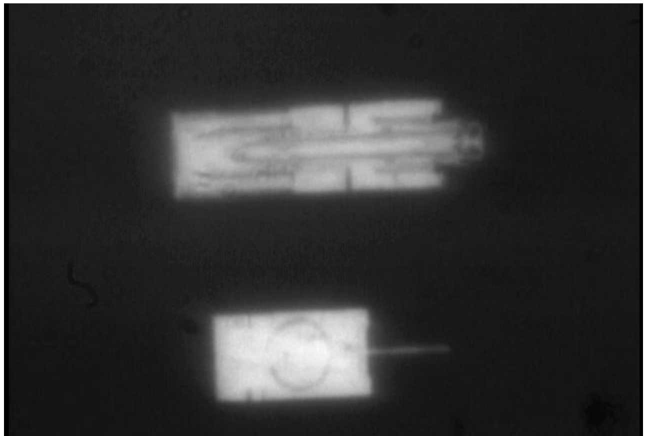
Adaptive Optical Zoom vs Digital (Electronic) Zoom

Digital Zoom is simply larger: no increase in resolution.





Digital Zoom Result



Active Optical Zoom Result

Active Optical Zoom accomplished by changing the voltages that were applied to the two SLMs.

NO MOVING PARTS

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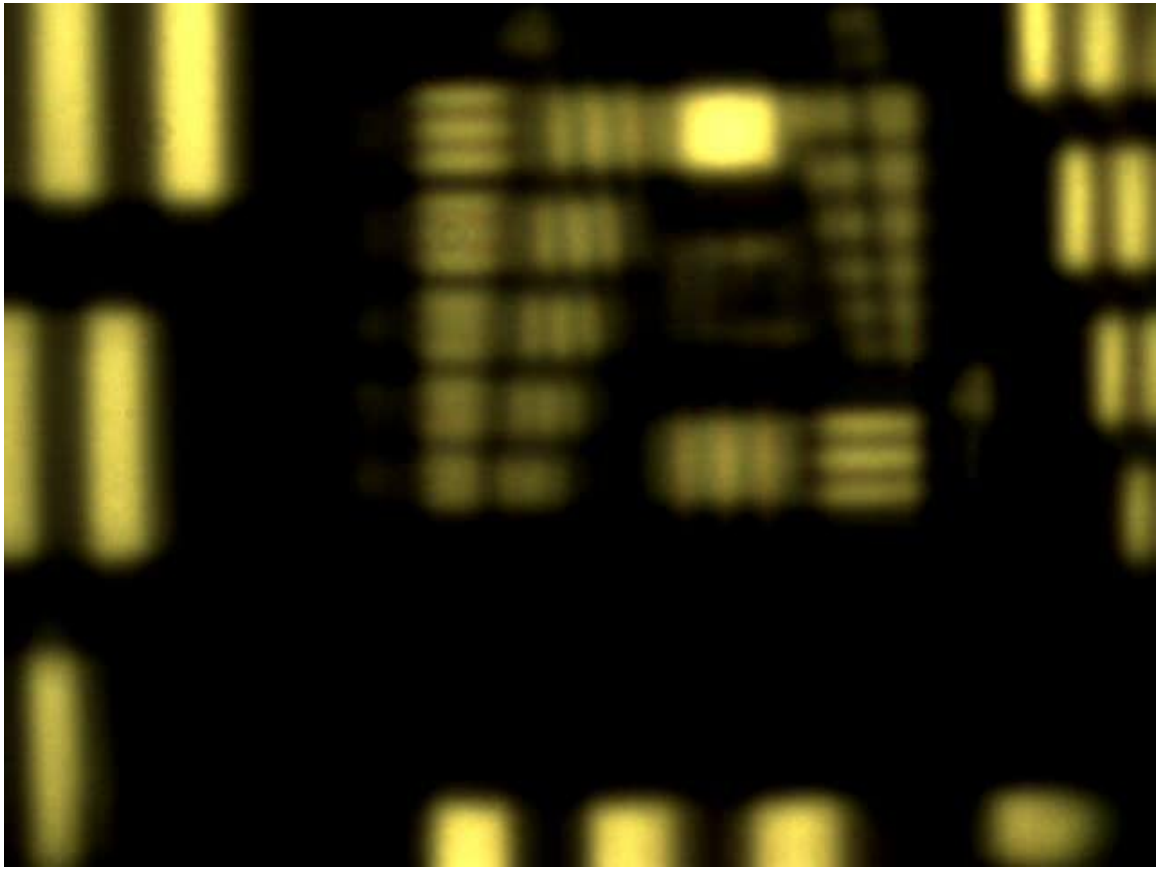
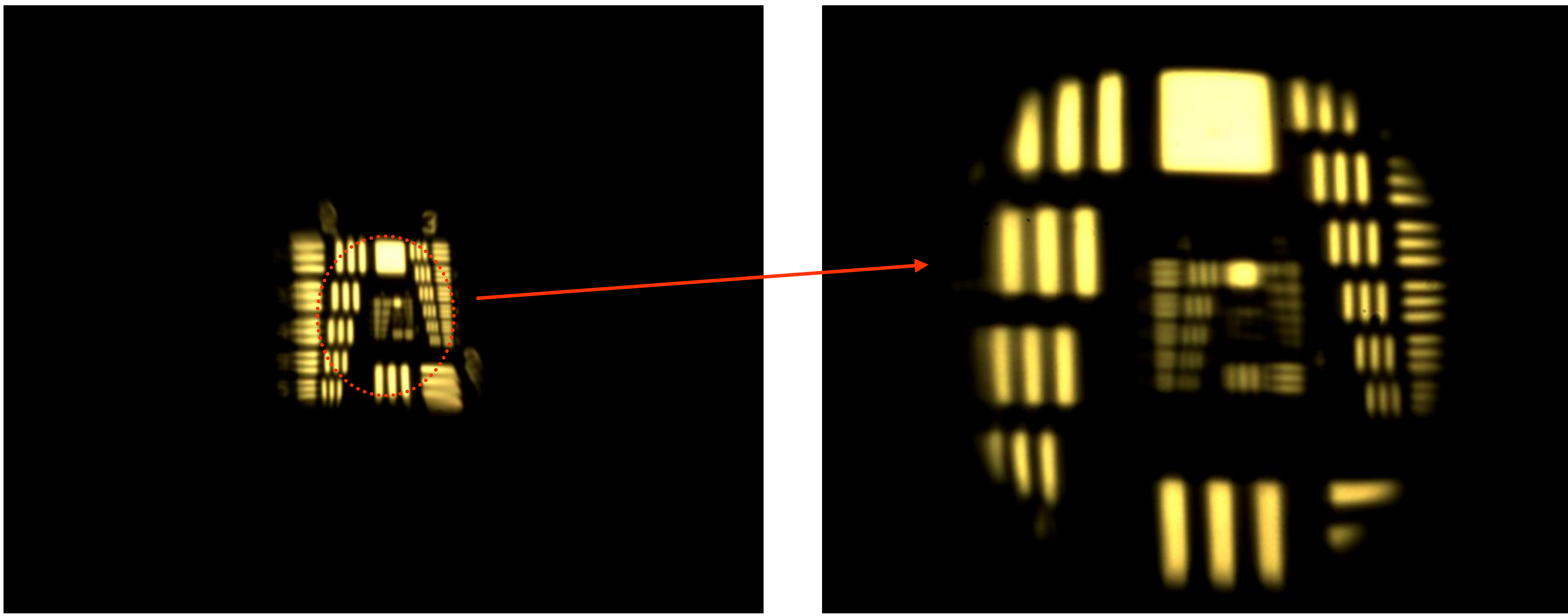
Continuous
All Reflective Zoom

4.5X Adaptive Optical Zoom System

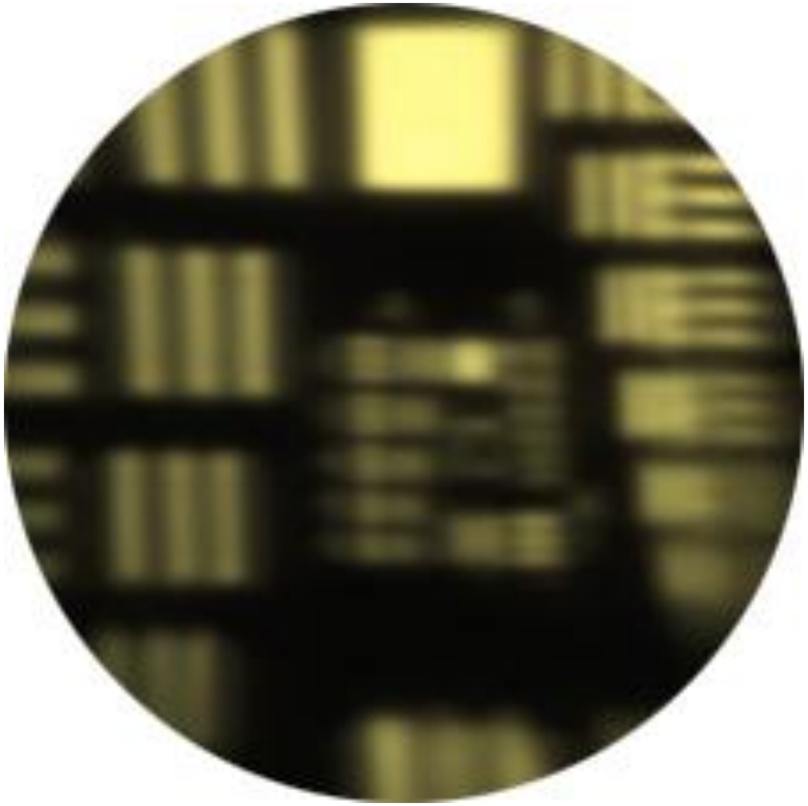


4.5X Adaptive Optical Zoom System

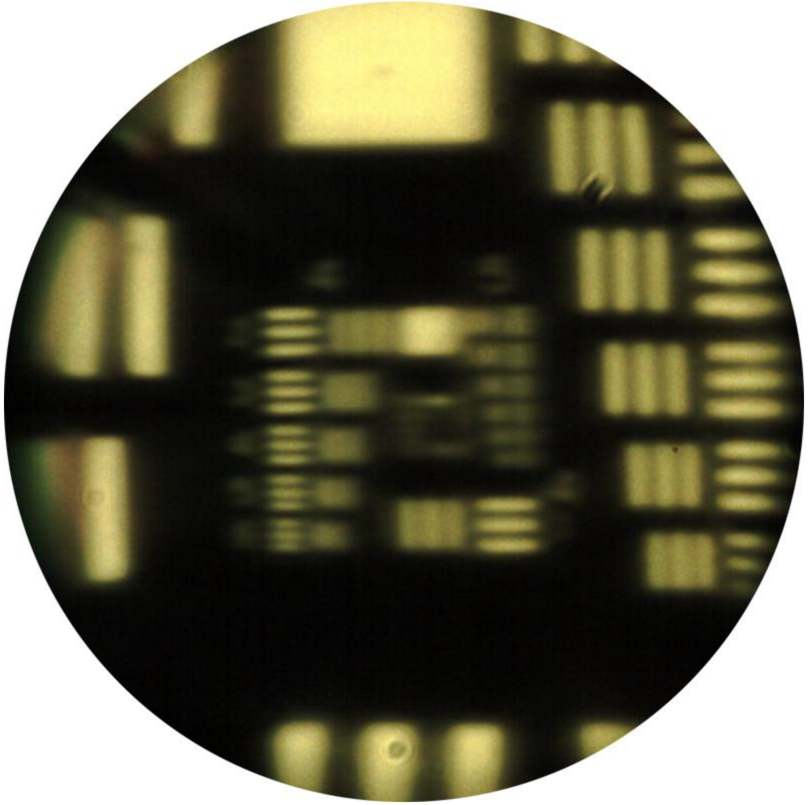


Adaptive Optical Zoom

Increase in resolution by almost 2X from 17.95 lp/mm to 32 lp/mm



Adaptive Optical Unzoomed



Adaptive Optical Zoomed

Sponsored by NRO/DII program and Sandia LDRD NP&A SMU

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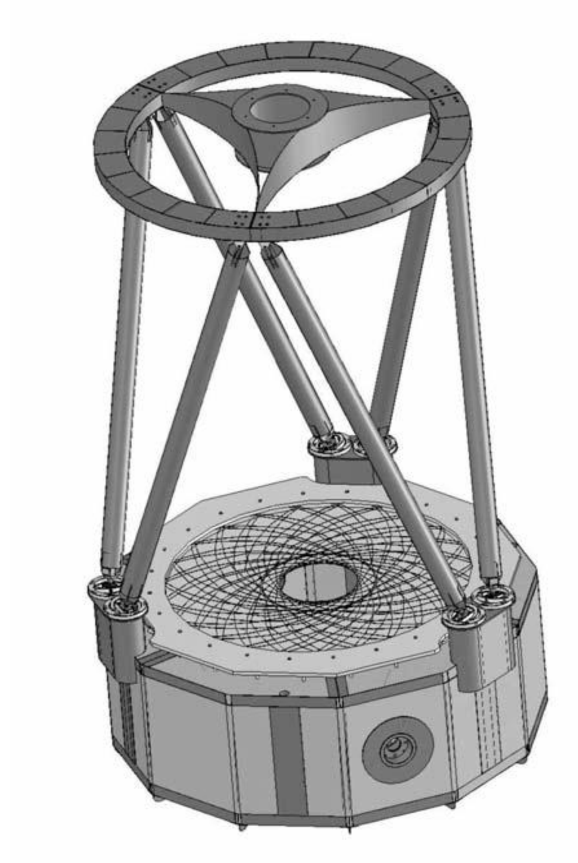
Large Aperture Composite Mirror Development

Prototype 16” CRFP telescope. This prototype is being developed for testing and capability demonstrations.



1.4 m design. This telescope is being developed for the upgrade of the Naval Prototype Optical Interferometer (NPOI) in Flagstaff, AZ.

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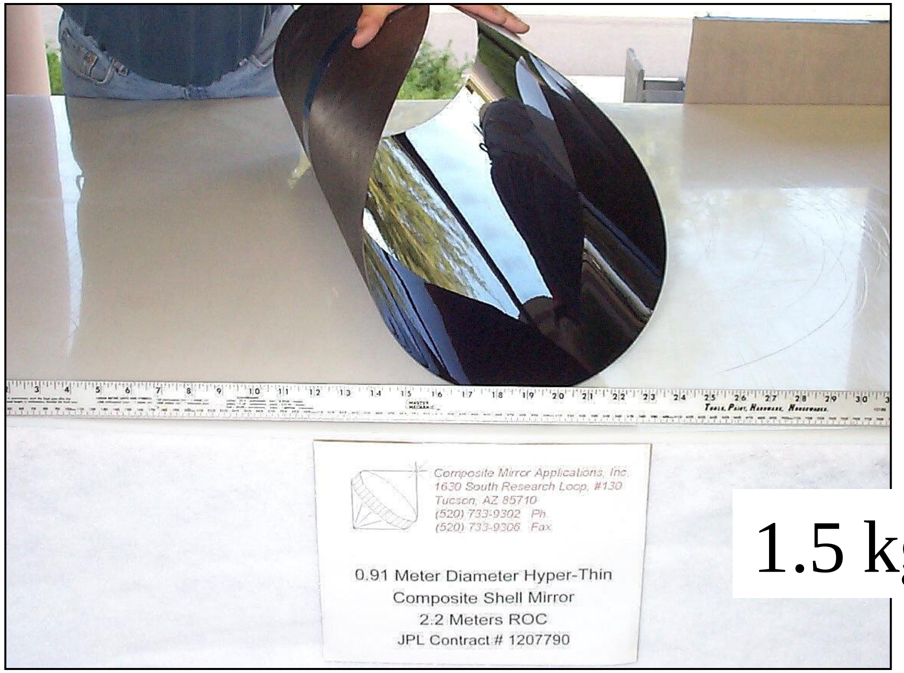
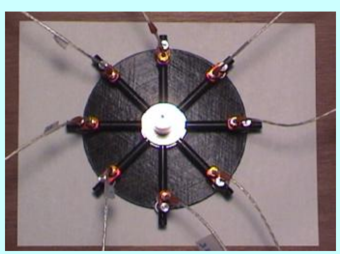
Carbon Fiber Reinforced Polymer Mirrors

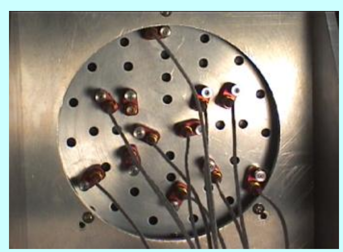
Composite Mirror Applications



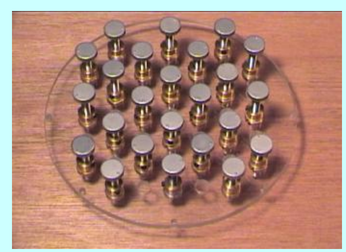
1.5 kg/m^2



8-Arm Moment Actuator System



Sparse Array of Force Actuators



Square Grid Force Actuator Array

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Why do we need large stroke?

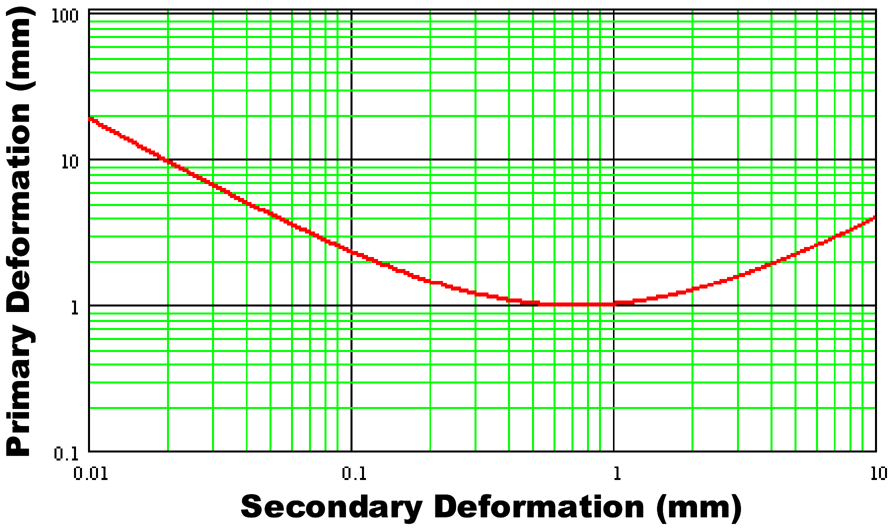
Mirror deformations from unzoomed to zoomed are related by

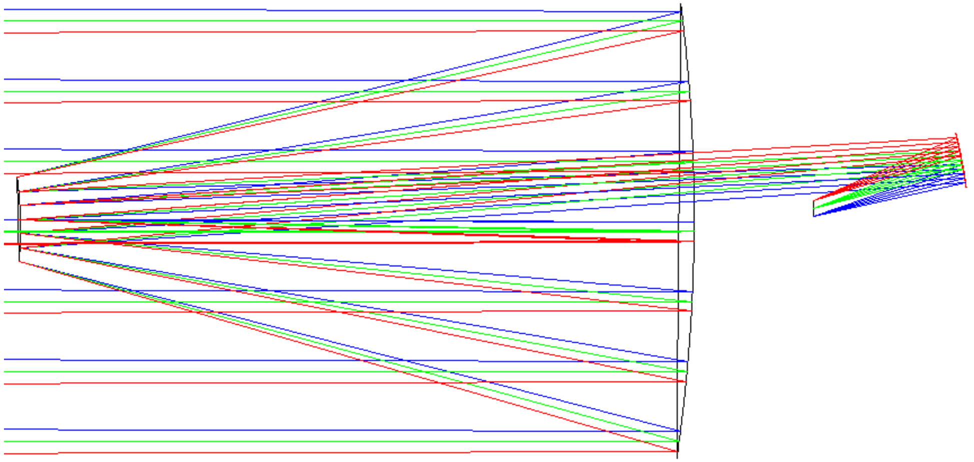
$$\Delta s_2 = \frac{H(r-1)}{2r} + \frac{(4\Delta s_1)^2 + H^2(r-1)^2}{16\Delta s_1 r}$$

Mirror #1 is closest to detector, and is the aperture stop
Mirror #2 is closest to the object.
Δs_2 is measured in the zoomed configuration.
r = zoom ratio
H = Lagrange invariant = ½D sinθ=w/4f#
D = Entrance pupil diameter
θ = half field of view
w = image height (full)
f#=f-number=focal ratio

Note: this relationship is independent of design details, and cannot be altered by using intermediate (fixed) lenses and mirrors.

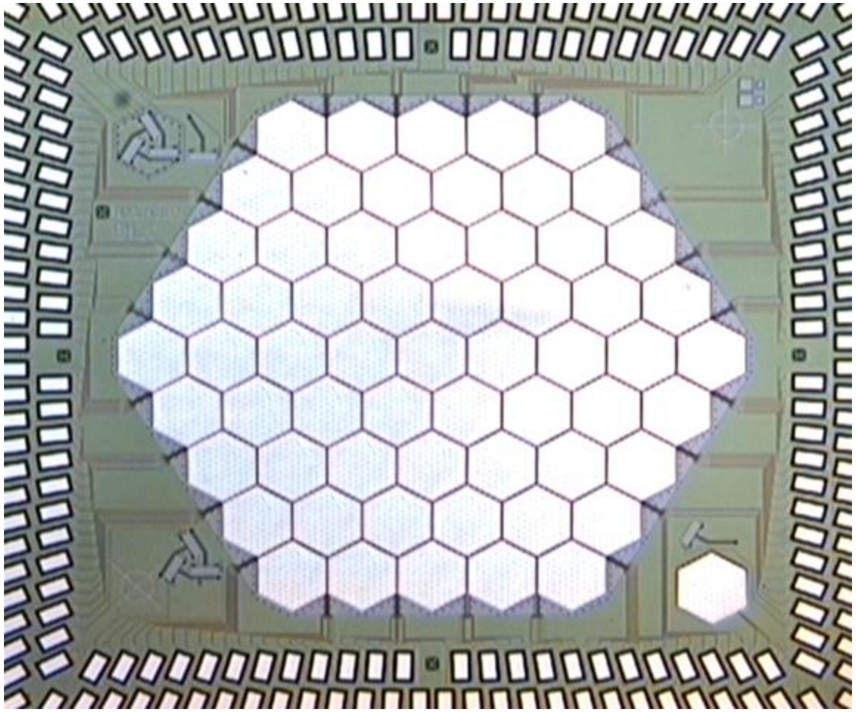
Required mirror deformation

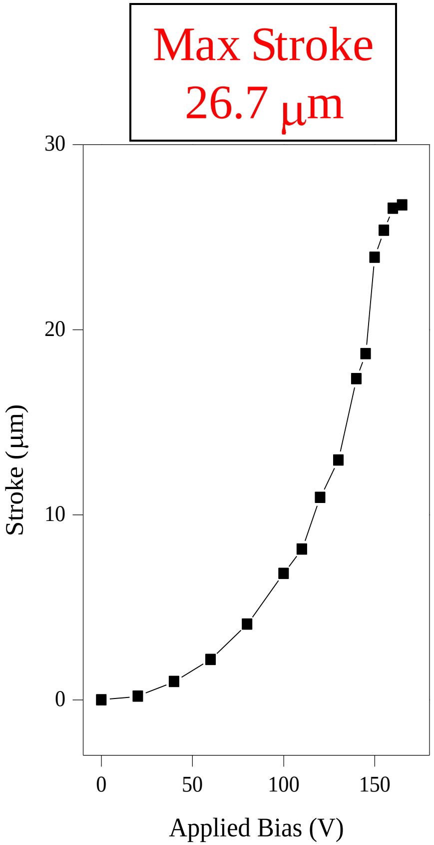


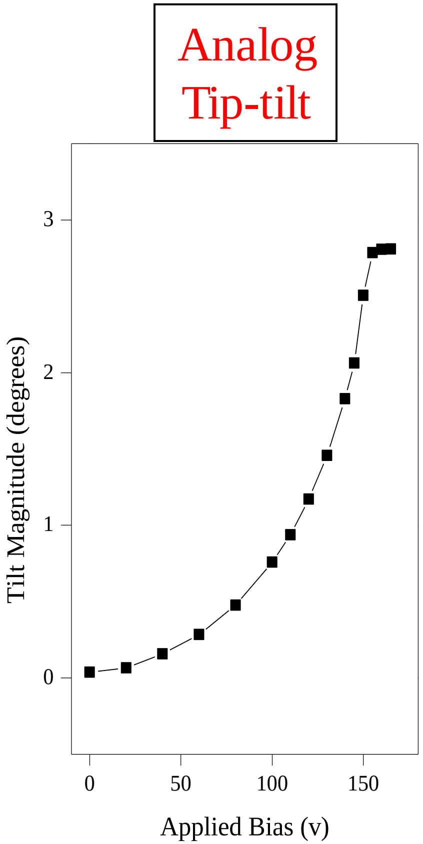


Primary mirror deformation as a function of secondary mirror deformation for a zoomed entrance pupil diameter of 1 *m*, a zoom ratio of 3X, and a FFOV of 1 degree.

SANDIA - Large stroke MEMS mirrors







Sandia (Bill Cowan and Olga Spahn) currently has only MEMS development with piston-tip-tilt analog control and 26.7 μm stroke

Large throw MEMS

rms roughness (includes ROC)

Veeco

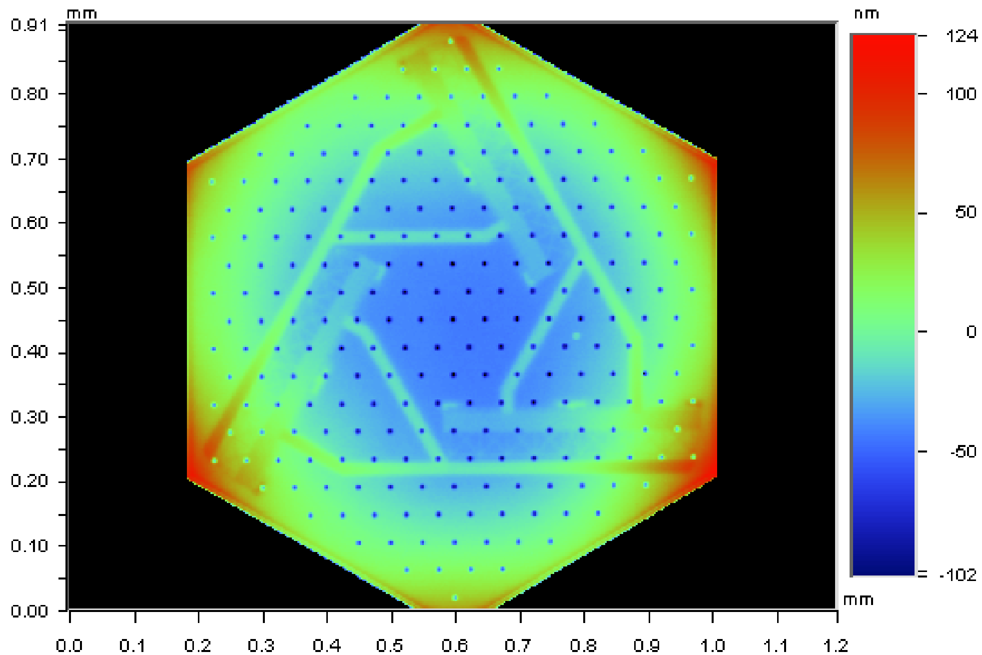
Mag: 5.2 X
Mode: PSI

Surface Data

Surface Statistics:
Ra: 23.79 nm
Rq: 29.73 nm
Rz: 211.83 nm
Rt: 226.07 nm

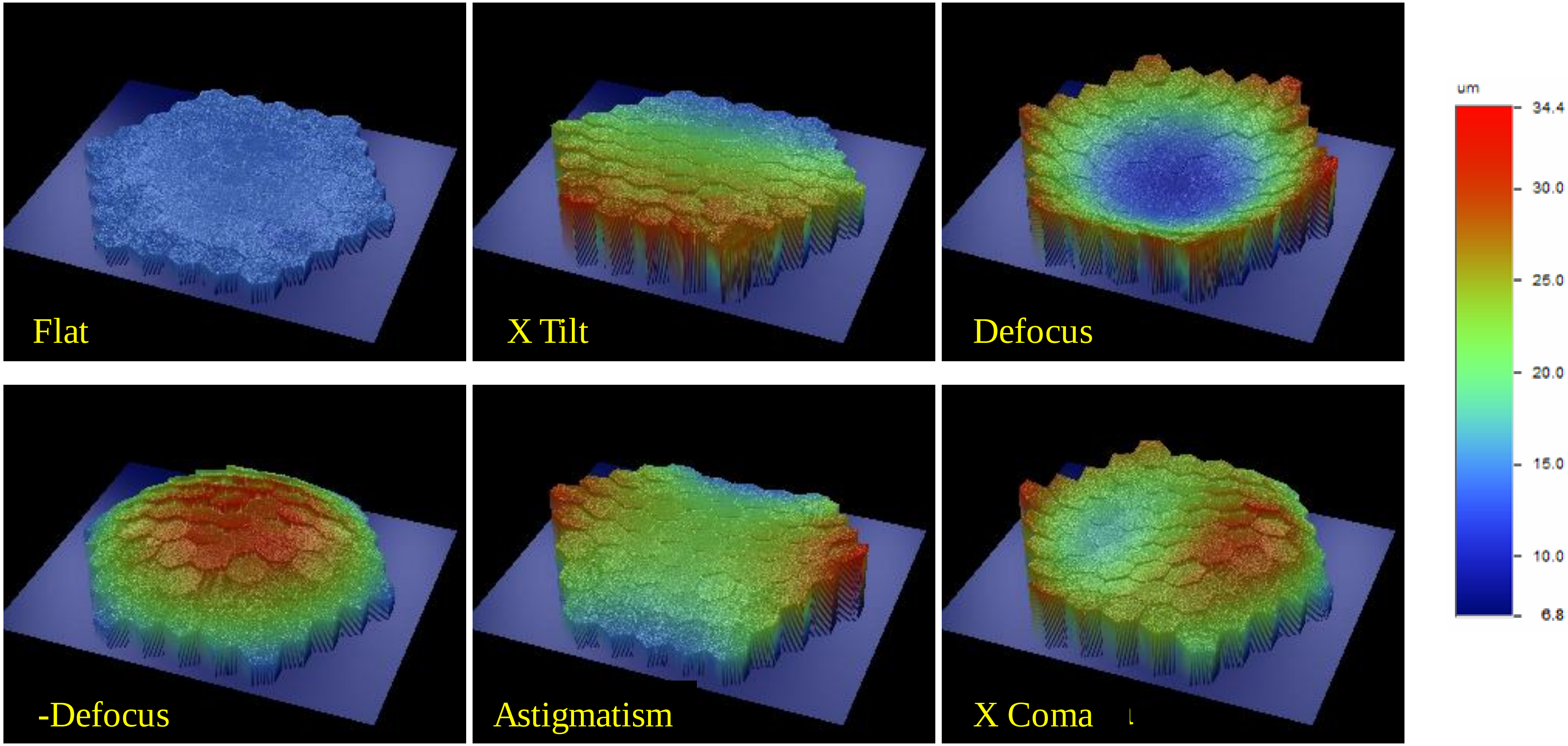
Set-up Parameters:
Size: 736 X 480
Sampling: 1.62 um

Processed Options:
Terms Removed:
Tilt
Filtering:
None



Title: H850_L1 ctr Al
Note: id6436 std P4

3D images of AO Zernikes on Current 61 Element Mirror

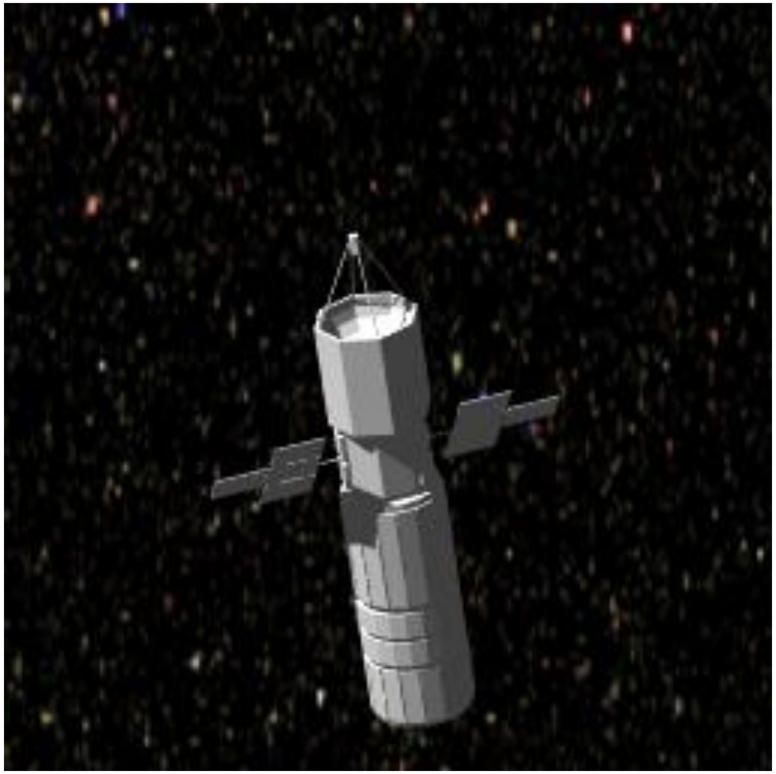


All images are on the same scale

Note: Mirrors are uncallibrated: all actuators controlled using a single voltage to deflection curve

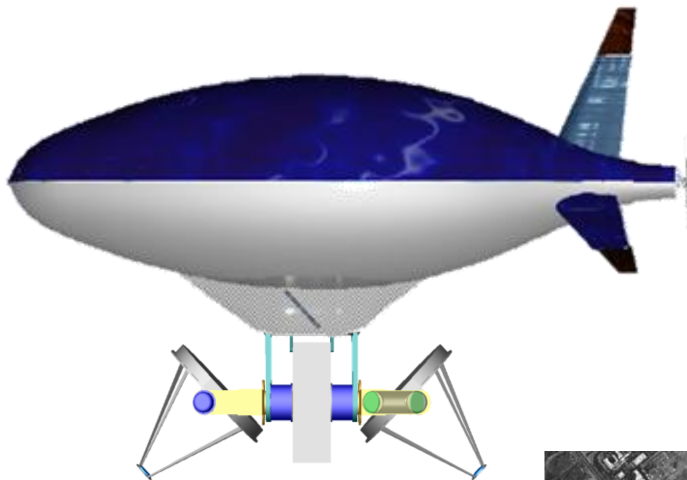
Potential Applications: Space-based SSA

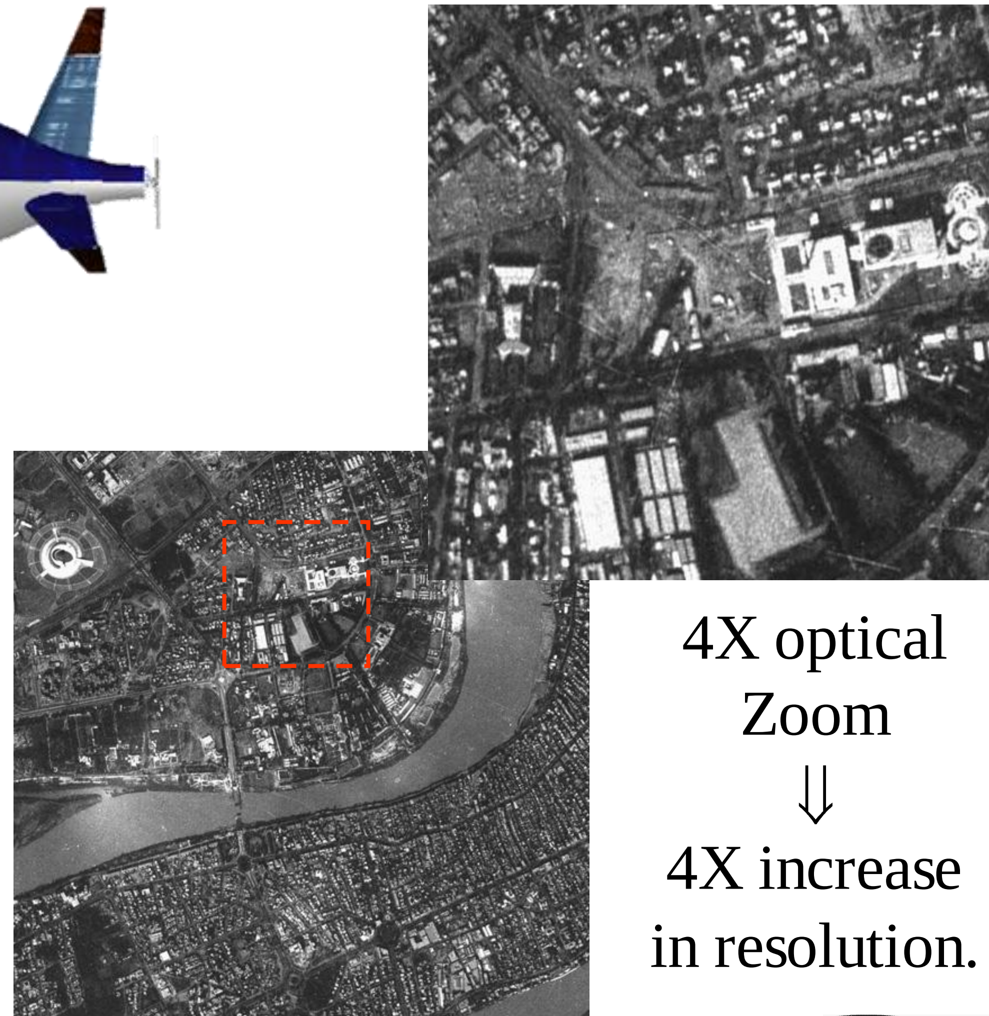
Surveillance/
Situational Awareness



Identification

Potential Applications:
Airship or Satellite Surveillance



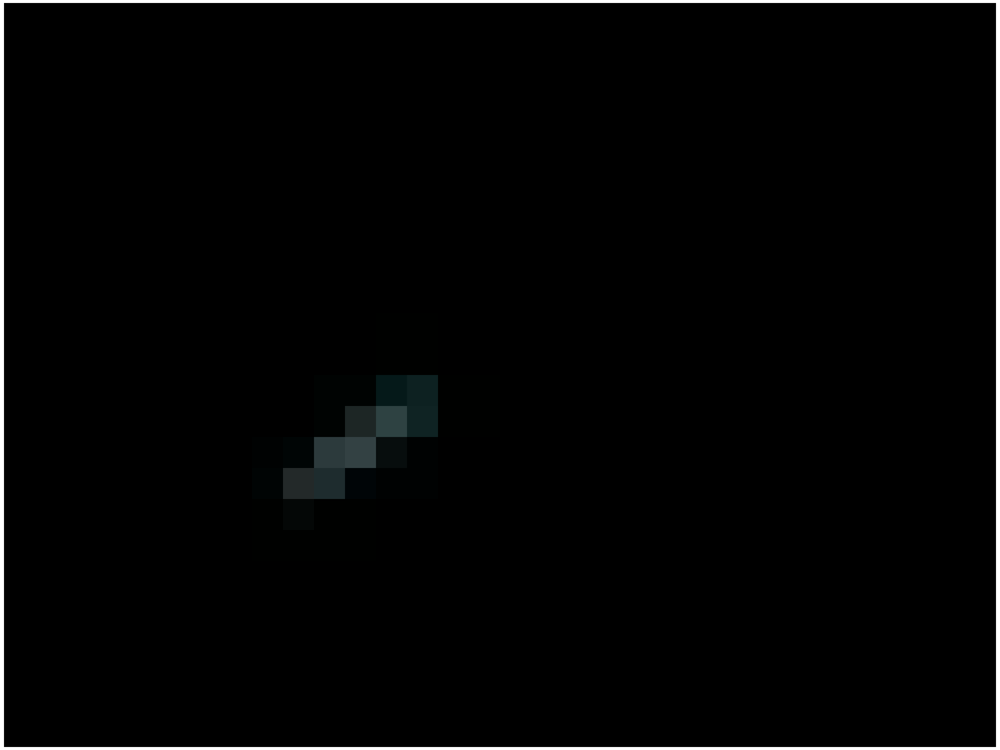


Single, wide field-of-view or multiple receivers may be used to cover wide areas. Nonmechanical zoom allows receiver(s) to adjust magnification in real-time as necessary for target identification/ tracking.

4X optical
Zoom
$\Downarrow$
4X increase
in resolution.

Potential Applications: Spot Size and FOV Optimization Concept – Missile Tracking

Animation of Missile Tracking (passive acquisition/active illumination/HE laser): With 10x Non-Mechanical Zoom



A typical tracking system has a fixed field-of-view and system magnification. We believe that tracking could be enhanced if the magnification could be adjusted in real time to optimize signal-to-noise on the detector. Also, reacquisition could be more easily accomplished (say after loss of tracking due to "jerk" motion) without having to switch back to acquisition mode. Simply increase the field-of-view iteratively until reacquisition is possible.

narrascape

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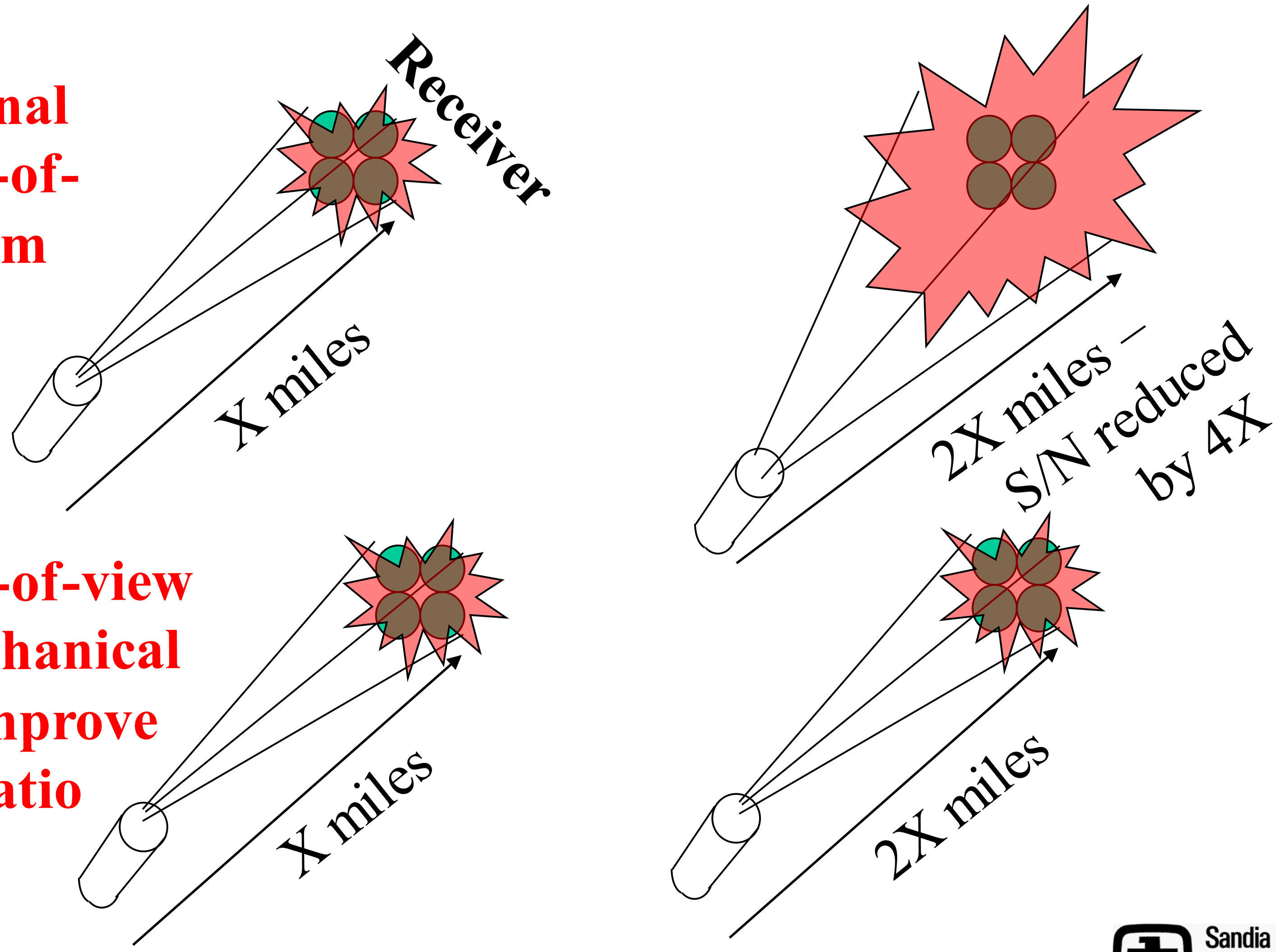
Adaptive Optical Zoom for laser comm variable FOV to optimize Signal/Noise

Conventional Fixed field-of-view system

Transmitter

Variable field-of-view With nonmechanical Zoom can improve the S/N ratio



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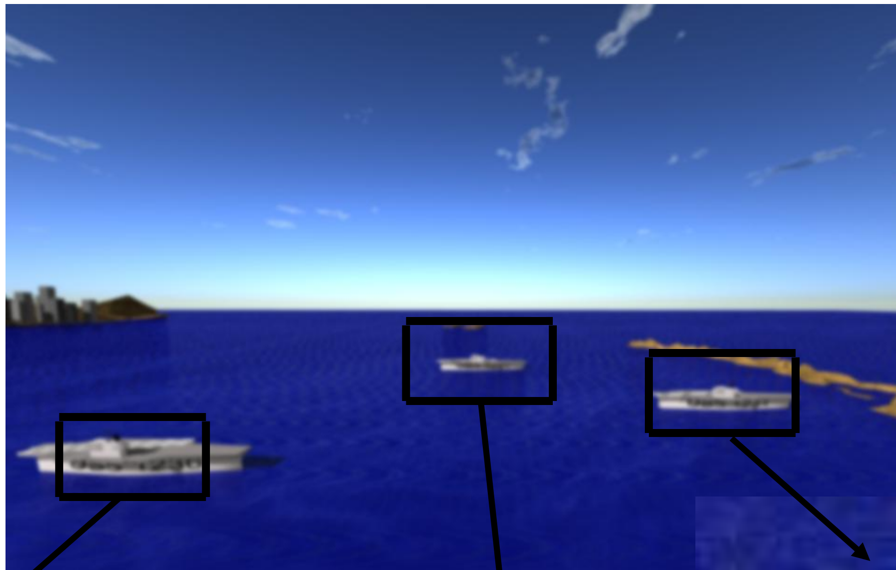
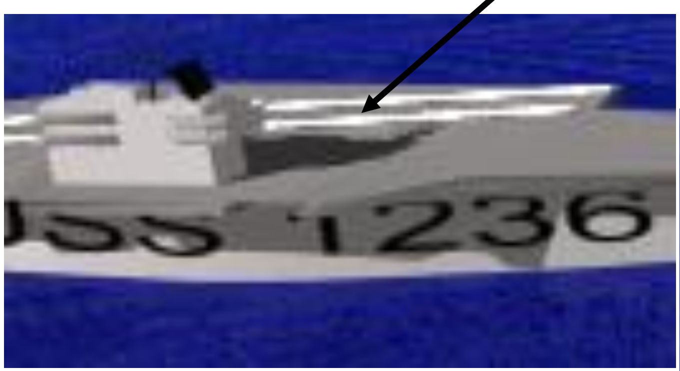
Harbor Surveillance and ship-to-ship secure communication

The Nonmechanical Zoom concept would use active optics to quickly zoom in on areas of interest with high spatial resolution interlaced with low spatial resolution wide field of view from the SAME sensor.



The technology proposed could scan between the four (and more) image contexts presented at speeds of at least video frame rates (30 Hz).



Acknowledgements

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Back Up Slide

Demonstration Design

Object

OKO Deformable Mirrors

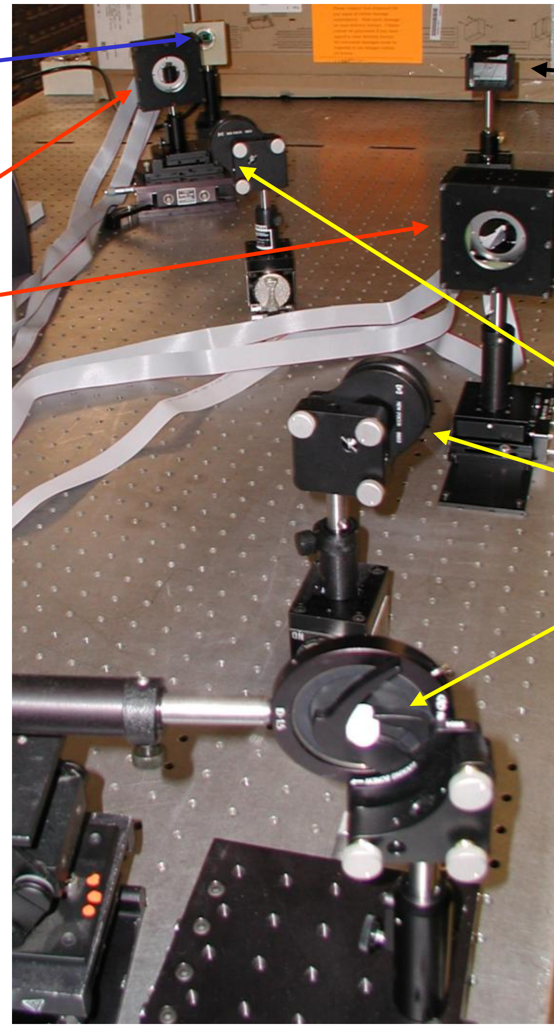
Static Mirrors

Three spherical mirrors, f = 1.0, 0.2, 1.0 m

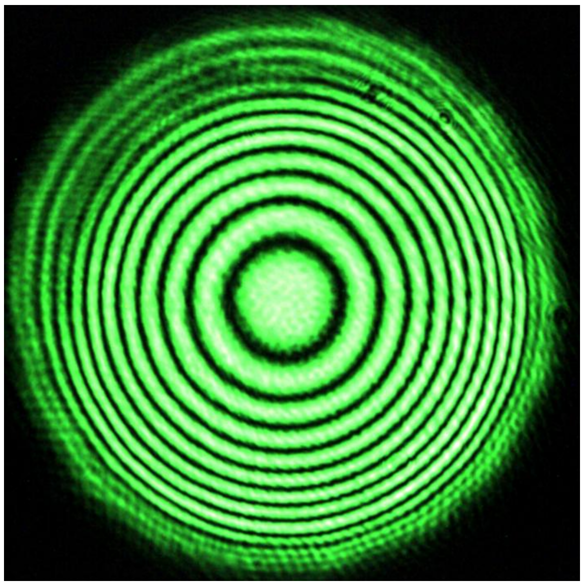
F/# = 40-80

FOV = 0.12°

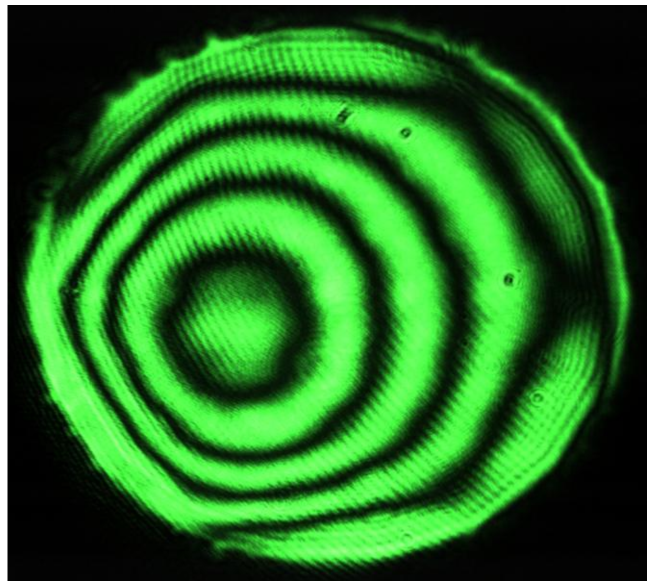
Experimental Layout



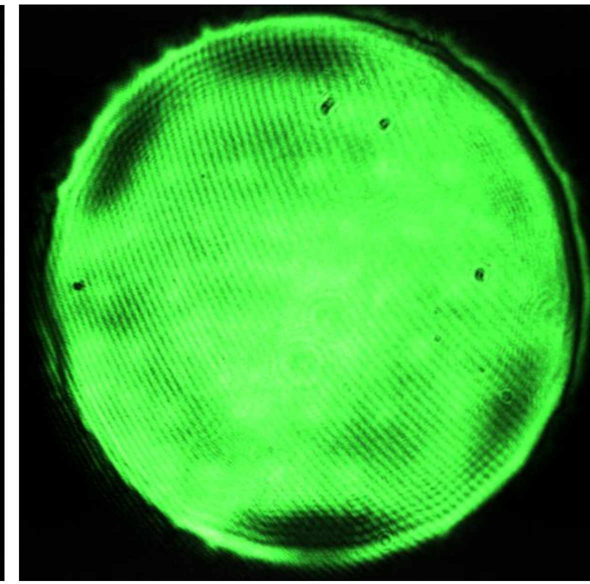
Correcting 37 Channel to f = 2.5m



No Voltage



Bias Voltage

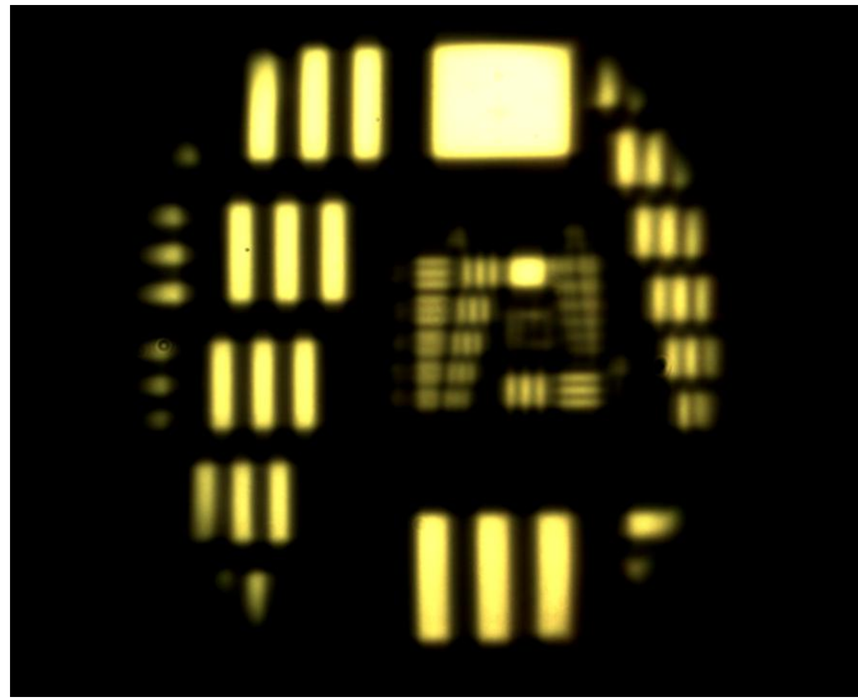


Corrected

$$\text{Sag} \cong y^2 / 2R$$

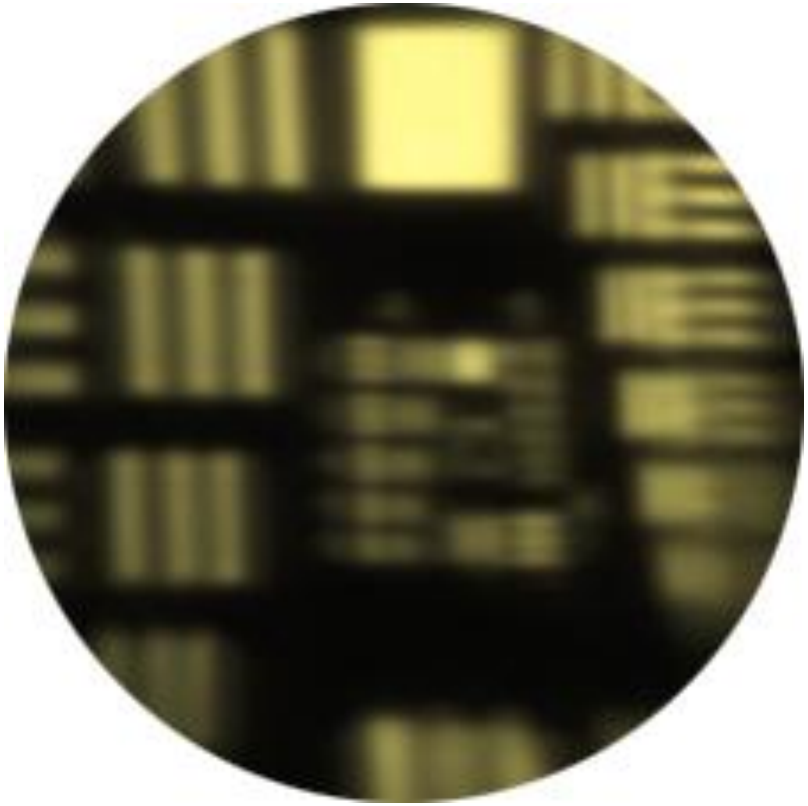
$$R = 5\text{m} \cong (7.5\text{mm})^2 / 2\,(10 * 0.532\mu\text{m})$$

Same system with Diffraction-Limited Static Mirrors

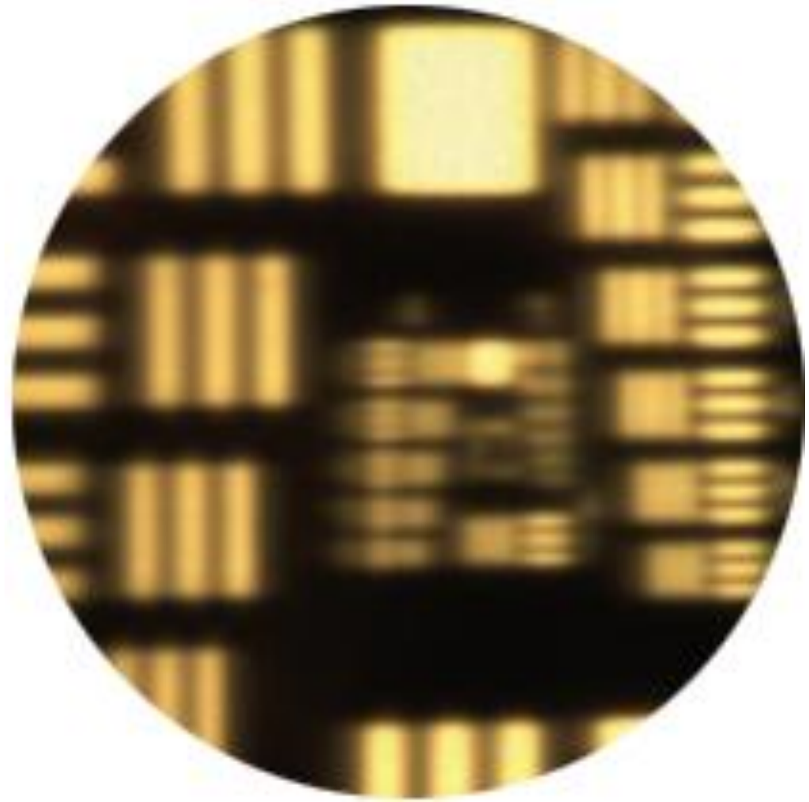


Unzoomed comparison

Diffraction Limited MTF < 10 % at Group 4/ Element 3 (20.16 lp/mm) in Unzoomed



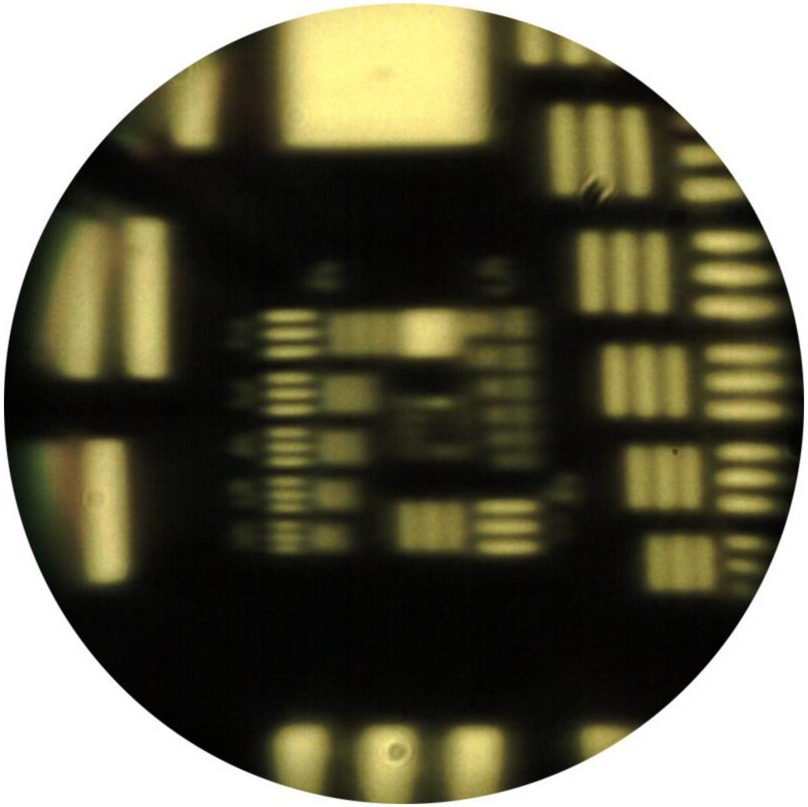
Adaptive Optical Unzoomed



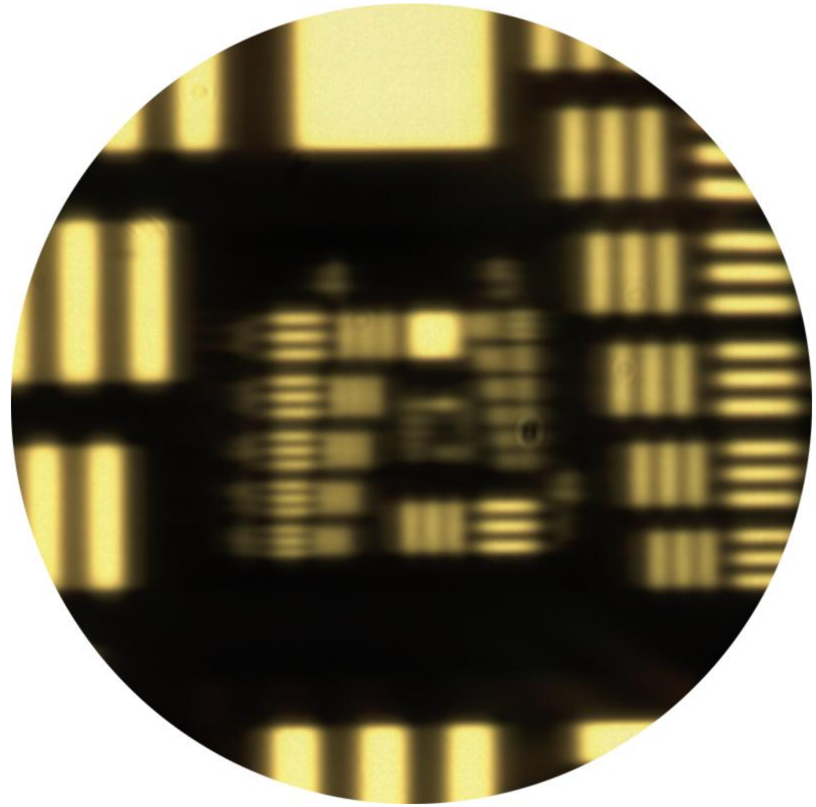
Static Optical Unzoomed

Zoomed Comparison

Diffraction Limited MTF < 10 % at Group 5/ Element 2 (36 lp/mm) in Zoomed



Adaptive Optical Zoomed



Static Optical Zoomed

Conclusions – Preliminary Study of Adaptive Optical Zoom Design Tradespace

- To preserve system numerical aperture (f-number) the entrance pupil must be stopped down by the ratio of the zoom in the unzoomed case.
- The second active mirror must be at an image of the aperture stop.
- For 1m class telescope with 1^{o} FOV, > 1 mm of throw is necessary on primary to maintain high image quality for both zoomed and unzoomed states IF we maintain the numerical aperture.
- For only 2 active mirrors, changing the numerical aperture between states sacrifices both illumination and image quality in the zoomed configuration and does not simply reduce the irradiance and image quality FOR THE UNZOOMED CASE ONLY as was hoped. Adding more active elements needs to be investigated.
- Auxiliary optics can reduce the overall length of the system, but cannot reduce the magnitude of the mirror deformations.
- Possible to use a fixed primary and place smaller active mirrors within a reimager to zoom the system – needs to be investigated.